Il Colle di Galileo

Out-of-equilibrium systems and planetary habitability

VI workshop of the TDE-NAI Focus Group

Location and date: Villa "Il Gioiello", Arcetri. Florence
October 14-16, 2013
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Abstract. The VI workshop of the "Thermodynamics, disequilibrium and evolution" Focus Group was held in the beautiful setting of *Villa il Gioiello*. This meeting focused on out-of-equilibrium systems, which could provide the conditions for the emergence of life, and on the use of thermodynamic instruments for the study of planetary habitability.

Keywords. Non-equilibrium thermodynamics, origin of life, planetary habitability.

The VI workshop on "Thermodynamics, disequilibrium and evolution" (TDE), a NASA Astrobiology Institute focus group, took place at Villa il Gioiello in October 2013. The TDE is intended to bridge the gap between researchers working on the theoretical and experimental aspects of the Origin of Life and astronomers deciding on future targets for the search for extraterrestrial life. In particular, the meeting focused on the entropy and energy requirements for life on planets and how these can provide precious hints for the selection of potentially habitable planets and environments in the cosmos.

Disequilibrium on a cellular scale is made possible by the cell membrane, which maintains favourable redox and pH gradients between the cell and the external environments. On a supracellular scale, disequilibrium conditions are created most visibly by colony-formers such as stromatolites and corals, which are multi-cellular (often symbiotic) aggregates on a local scale. On a planetary scale, biological processes such as photosynthesis can establish and maintain disequilibrium conditions. A source of energy for life depends upon disequilibrium between the cell and the environment. Because life is not only able to maintain a state of disequilibrium, but can also change the environment through the presence of disequilibrium, making its presence detectable remotely at large distances from the Earth. The TDE Focus Group seeks to integrate the astrobiology community around this paradigm to search for signs of life in the universe.

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Fig. 1. Chemical gardens grown from silicates (source: wikicommons). Chemical gardens are steady-state structures formed by insoluble metal compounds (mostly silicates) in water, which form semipermeable membranes capable of growing into plant-like shapes as a result of ionic osmotic pressure. Chemical gardens are useful for studying the abiotic formation of structures similar to living ones.

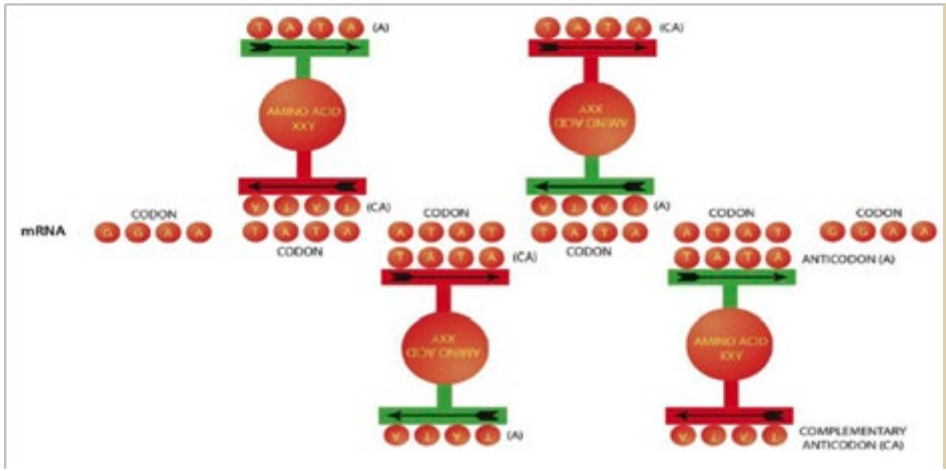

Fig. 2. Towards a mathematical, statistical and entropic interpretation of the evolution to present RNA. The figure shows a symmetric tRNA adaptor that can read mRNA in both directions. When the adaptor reads palindromic codons it recognizes the same codon (tessera), in the example TAAT (From "On the origin of the mitochondrial genetic code: Towards a unified mathematical framework for the management of genetic information", Gonzales, Giannerini, Rosa, Nature Proceedings 2012).

The VI workshop of the TDE Focus Group provided the occasion for update on the state of the art of each participant's research and to discuss possible synergies among complementary fields. It also offered an opportunity for the TDE community to meet representatives of the Italian Astrobiology Society and to strengthen the participation of European scientists in the Focus Group.

The latest results about Mars and the presence of life were shown after the data release of the NASA mission "Curiosity". A focus study of exo-planets and planetary atmospheres, in connection with recent and future missions, provided the opportunity to discuss the use of thermodynamics for the assessment of planetary habitability.

Results were presented about new experiments with chemical gardens and the measurement of the electrochemical potential in hydrothermal vent-like mineral matrices. Related to this research, new experiments have been carried out on "brinicles" or "brine icicles", that is self-growing ice structures created in conditions of intensely cold water temperature and intense salinity. Both studies offer important cues about the conditions for the emergence of complex chemical structures and processes, such as living systems, in the early Earth oceans or, in the case of the brinicles, in cold traps and icy moons in the solar system. These projects involve the collaboration of scientists from the US, Spain, the UK and Italy.

Furthermore, an interesting application of the hydrothermal vent-like analogues was a kind of simplified fuel cell. An interesting and controversial discussion arose regarding the thermodynamic meaning of both the stability and statistics

of RNA structure and assembly. Researchers from the University of Bologna and from the CNR showed how entropic optimization could force RNA replication to be based on a specific number of nucleobases and genes.

Interesting results were presented on ATP metabolism, recombination and prebiotic chemistry, as well as reports about Mars analogue field trips in Tunisian desert areas. Theoretical thermodynamics studies have begun to link findings about Earth conditions (past and present) for the emergence of life to the study of planetary habitability. Finally, the TDE workshop offered astronomers, chemists and physicists the chance to discuss new definitions of life and, as a consequence, the instruments for detecting habitability in other planetary bodies.

The meeting was attended by 15 participants, including students from the Department of Physics and Astronomy of the University of Florence and from the Scuola Normale Superiore of Pisa. The organizers of the Arcetri Astrophysical Observatory and researchers at JPL-CalTech and at IACT in Granada agreed to create a European focus group on chemical gardens and brinicles and their link with the origin of complex structures and life. As a result, three collaborations were established with the goal of exchanging ideas and results in the coming months. The Italian astrobiology community contributed with interesting results that motivated NASA TDE members to continue and extend their collaboration. Following the workshop in Arcetri, the co-chairs Laurie Barge and Eugenio Simoncini proposed organizing the next TDE workshops in Brazil and Japan, in 2014 and 2015 respectively.